Coastal Engineering Technical Note

PREDICTION OF ERODED VERSUS ACCRETED BEACHES

PURPOSE: To present revised procedures for predicting whether a beach profile of a specified sand size will tend to erode or accrete through cross-shore transport produced by incident waves of given height and period. This CETN supplements pages 4-83 through 4-85 of the Shore Protection Manual (SPM 1984) and is a revision of a previous CETN of the same title dated June 1988, updated to include 100 new field data points. This information can be used to evaluate the stability of an existing beach or a beach fill, as well as assess the cross-shore direction of movement of artificial sand bars placed in the nearshore (cf. Dredging Research Program Technical Note DRP-5-02).

BACKGROUND: The term "erosion" describes removal of material from the visible beach by wave action, often to produce a gentle slope in the surf zone and one or more large longshore bars in the offshore. The term "accretion" describes sand accumulation in the form of one or more berms on the visible beach and, typically, a steep profile in the surf zone. Although the terms erosion and accretion commonly refer to the response of the visible beach, material is not necessarily lost from or gained by the system, but only displaced and rearranged along the beach profile extending from the dune crest to a water depth where no significant net sediment movement occurs. Surveys of wide longshore and cross-shore extent are required to determine if a beach has experienced a net loss or gain of material. Discussion is restricted to beach profile change produced by waves normally or near-normally incident to an open coast.

Laboratory and field measurements have indicated that the following variables determine in great part whether a beach will erode or accrete: deepwater wave height, H_o ; wave period, T ; and sediment particle fall speed, w (obtained from knowledge of the median grain diameter d_{50} and water temperature). The three quantities H_o , T , and w can be arranged in several ways in the form of two nondimensional ratios. The two nondimensional ratios used here are,

deepwater wave steepness, $S_o = H_o/L_o$

deepwater fall speed parameter, $N_o = H_o/wT$

in which $L_o = gT^2/2\pi$ is the wavelength in deep water, and g is the acceleration due to gravity ($g = 9.81$ m/sec^2 $= 32.2$ ft/sec^2). In metric units, $L_o = 1.56\ T^2$ (m), whereas in American Customary units, $L_o = 5.12\ T^2$ (ft), for which T is given in sec.

For predominantly quartz sand beaches, a sieve-determined median diameter may be an adequate description of grain size. However, the sediment particle fall speed w provides a better representation of "hydraulic" grain size and can account for the effect of water temperature (water viscosity) for which, as an example, lower temperatures would tend to keep sand in suspension. Sand fall speed may be calculated by Equations 4-7 to 4-9 of the SPM (1984) (see also, CETN II-4), and a short table of fall speed values based on those equations is given in Table 1.

PREDICTION METHODS: Two criteria are presented that were originally developed based on two sets of laboratory data (labeled CE and CRIEPI in Fig. 1) involving quartz sand, wave and beach dimensions of prototype scale, and monochromatic waves (Larson and Kraus 1989). For this revised CETN, the criteria were further evaluated using a field data set of 100 erosion and accretion events compiled from the literature describing 31 beaches around the world (Kraus, Larson, and Kriebel 1991).

The prototype-scale laboratory tests provide accurate data obtained under controlled conditions and are superior to field observations in that possible factors not necessarily related to the beach sediment and normally incident waves, such as wave direction, lateral boundary conditions, tide and long-period surf beat, are absent. The disadvantage of laboratory tests performed with monochromatic waves is that the appropriate equivalent statistical wave (for example, root-mean-square wave height, mean wave height, significant wave height, etc.) is not known without reference to field data. In comparison of erosion and accretion predictors based on the laboratory and field data, the empirical factors in these criteria retained the same approximate value if the mean wave height was used in the evaluation. Under the standard assumption of a narrow-banded wave spectrum, for which a single dominant peak in wave height is present, the mean wave height is proportional to the significant wave height by a known amount, and the criteria presented here were modified to allow use of significant wave height. Also, the period associated with the peak in the spectrum should be used in field applications. If knowledge of the spectral peak period is lacking, the period associated with the significant wave height should be used. Because this CETN is targeted at field applications, in what follows H_o is the significant deepwater wave height, and T is the spectral peak wave period.

Criterion 1: This criterion (Larson and Kraus 1989) is expressed as $S_o = M\ N_o^3$, in which the empirical factor M = 0.00070 for mean wave height (or for monochromatic-wave laboratory experiments of large scale), and M = 0.00027 for significant wave height in field applications. This criterion is shown as the diagonal line drawn (M = 0.0007) in Fig. 1 together with the data from the monochromatic-wave laboratory tank experiments. Wave steepness and fall speed parameter combinations producing a prominent berm (accretion) are labeled with open symbols, and combinations giving a prominent bar (erosion) are labeled with filled symbols. The diagonal line separates regions occupied by erosion and accretion.

Fig. 2 shows the same criterion (M = 0.00027) plotted against the field data set (using significant wave height), in which open and filled symbols again represent accretionary and erosional events, respectively. Although there is some crossing of accretionary and erosional events about the solid diagonal line, the criterion distinguishes the main body of the data for the two beach responses. The dashed lines represent predictions obtained with one-half and double the value of the empirical coefficient and provide a measure of reliability of the prediction. Criterion 1 may be summarized as follows for field applications:

$$\begin{array}{llll} \text{If } S_o > 0.00014\ N_o^3, & \text{then} & \text{ACCRETION} & \text{is highly probable.} \\ \text{If } S_o > 0.00027\ N_o^3, & \text{then} & \text{ACCRETION} & \text{is probable.} \\ \text{If } S_o \leq 0.00027\ N_o^3, & \text{then} & \text{EROSION} & \text{is probable.} \\ \text{If } S_o < 0.00054\ N_o^3, & \text{then} & \text{EROSION} & \text{is highly probable.} \end{array} \tag{1}$$

Criterion 2: Observing the trend in the data in Figs. 1 and 2, a vertical line expressed by the simple equation $N_o = 2.0$ (Fig. 1, laboratory data, mean wave height) and $N_o = 3.2$ (Fig. 2, field data, significant wave height) well separates accretionary and erosional events. By including an error estimate formed by decreasing and increasing the empirical coefficient by 25 percent, the following criterion is obtained for field use:

$$\begin{array}{llll} \text{If } N_o < 2.4, & \text{then} & \text{ACCRETION} & \text{is highly probable.} \\ \text{If } N_o < 3.2, & \text{then} & \text{ACCRETION} & \text{is probable.} \\ \text{If } N_o \geq 3.2, & \text{then} & \text{EROSION} & \text{is probable.} \\ \text{If } N_o > 4.0, & \text{then} & \text{EROSION} & \text{is highly probable.} \end{array} \tag{2}$$

The parameter N_o was popularized by Dean (1973) in an article devoted to prediction of erosion and accretion and is sometimes called the "Dean number." Wright *et al.* (1984) used average values of N_o to explain changes in beach state between and including episodes of erosion and accretion. Based on 6-1/2 years of daily observations at three beaches in Australia, Wright *et al.* found that accretion tended to occur if $N_o < 2.3$ and erosion if $N_o > 5.4$, in general agreement with Eq. 2.

DISCUSSION: Errors in the criteria can enter in three ways. First, the wave height, wave period, and sediment fall speed may be incorrectly estimated. The error bands stated above were developed by assuming a 10 percent error in each of these quantities (Kraus, Larson, and Kriebel 1991). Second, factors not directly related to H, T, and average w, such as the tide, surf beat and associated large runup, and variable grain size across the profile, can produce beach change, invalidating the criteria. Third, longshore variability may dominate or mask beach change induced by cross-shore transport. Longshore variability includes variations in the incident waves produced by an irregular offshore bathymetry, variations in dune size and composition, three-dimensional circulation patterns containing rip currents, and combined effects of oblique wave incidence and littoral controls such as jetties and groins. The third condition indicates that the criteria presented here are most applicable to straight stretches of beach distant from inlets, jetties, groins, and other coastal structures.

It is noted in Fig. 2 that the two criteria do not cover exactly the same domains, and regions exist in the vicinities of the upper and lower ends of the diagonal line where the criteria will give conflicting results. For example, at the upper end of the diagonal, there are values of wave steepness and fall speed parameter such that Criterion 1 predicts accretion to be highly probable, whereas Criterion 2 predicts erosion highly probable. This region corresponds to steep waves and relatively large grain size (or high fall speed). Unfortunately, the available field data do not provide guidance as to which prediction is correct. Because Fig. 1 indicates a trend that better supports Criterion 1, at present Criterion 1 is recommended over Criterion 2 in situations of conflicting predictions.

COMPUTER PROGRAM: A program implementing and automating evaluation of Criteria 1 and 2 has been developed for use on IBM-compatible personal computers (PCs). The program allows input of wave height and period in deep water or in finite depth water and shoals the wave by linear-wave theory to determine its height in deep water. The sand fall speed is also calculated and output as a function of water temperature and median grain size. The program, called "ON_OFF," can be obtained from the Automated Coastal Engineering System shareware network or by contacting the author of this CETN at the telephone number given in the information section below.

Table 1. Short Table of Fall Speed Values (m/sec) (Quartz Grains)

Water Temperature Deg C	Grain Size, mm					
	0.15	0.20	0.25	0.30	0.35	0.40
10	.016	.023	.029	.035	.042	.048
15	.017	.024	.030	.037	.043	.050
20	.018	.025	.032	.039	.046	.053
25	.019	.026	.034	.041	.049	.055

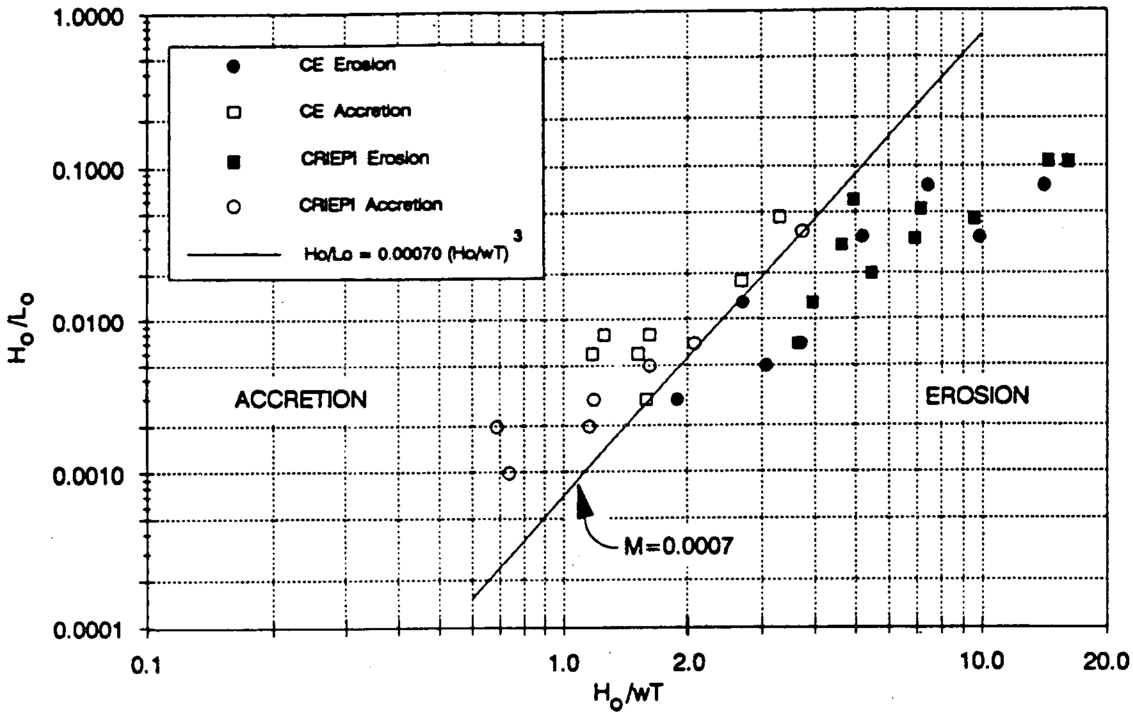

Fig. 1. Criterion for distinguishing bar and berm profiles; large tank data, monochromatic waves (Larson and Kraus 1989)

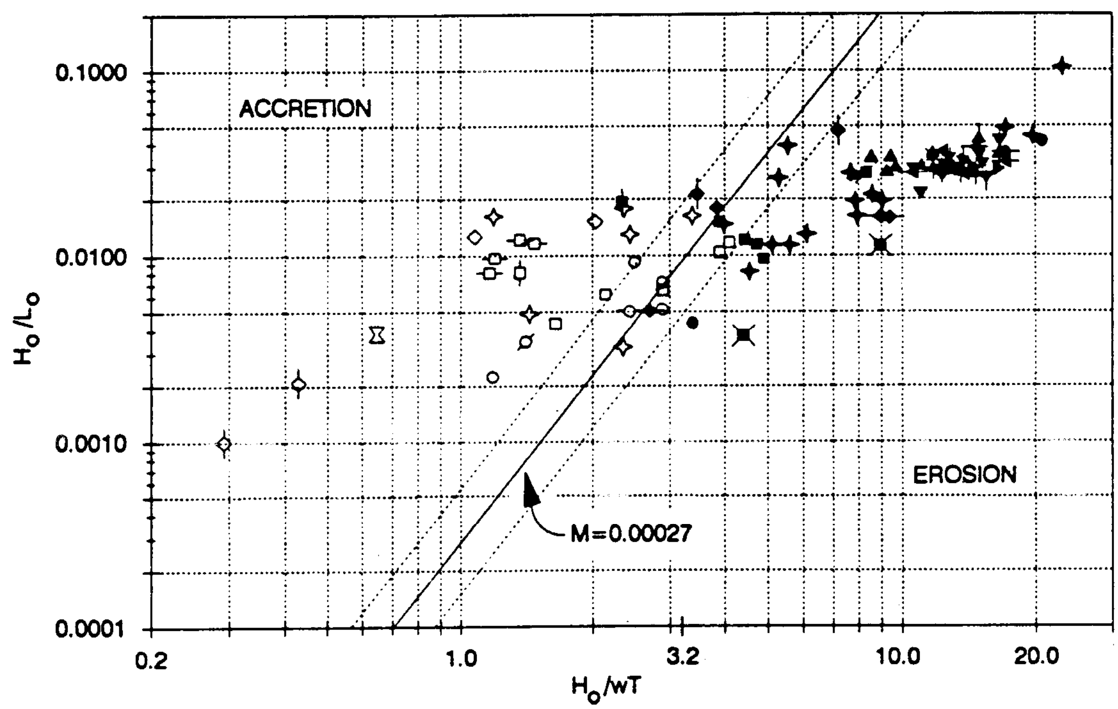

Fig. 2. Criterion for distinguishing bar and berm profiles; field data, significant wave height (Kraus, Larson, and Kriebel 1991)

******************************** EXAMPLES ********************************

PROBLEM: Determine, using the criteria presented, whether a beach of specified (quartz) sand grain size will experience erosion or accretion for three different wave conditions and two sand sizes. Assume that the water temperature is 20 deg C.

Example 1:

GIVEN: [A] $d_{50} = 0.2$ mm [B] $d_{50} = 0.4$ mm

$H_o = 1$ m $H_o = 1$ m

$T = 7$ sec $T = 7$ sec

SOLUTION

a) calculate L_o (metric units)

$$L_o = 1.56T^2 = 1.56(7)^2 = 76.5 \text{ m}; \quad S_o = H_o/L_o = 1/76.5 = \underline{0.013}$$

b) read w from Table 1

[A] $w = \underline{0.025 \text{ m/sec}}$

$$N_o = H_o/wT = 1/(0.025*7) = 5.7; \quad N_o^3 = \underline{185.2}$$

[B] $w = \underline{0.053 \text{ m/sec}}$

$$N_o = H_o/wT = 1/(0.053*7) = 2.7; \quad N_o^3 = \underline{19.7}$$

c) evaluate criteria for each situation

[A]

Criterion 1:

$$S_o = \underline{0.013} < 0.00054\ N_o^3 = 0.00054*185.2 = 0.10$$

indicates erosion highly probable

Criterion 2:

$$N_o = 5.7 > 4.0$$

indicates erosion highly probable

[B]

Criterion 1:

$$S_o = \underline{0.013} > 0.00014\ N_o^3 = 0.00014*19.7 = 0.0028$$

indicates accretion highly probable

Criterion 2:

$$N_o = 2.7 < 3.2$$

indicates accretion probable

The two criteria have shown that the finer sand size beach will erode and the coarser sand beach will accrete under the given wave condition.

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ADDITIONAL INFORMATION: For additional information, contact Dr. Nicholas C. Kraus, Research Division, Coastal Engineering Research Center, at (601) 634-2018.

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